Blind Channel Estimation based on Hadamard Matrix Interstream Transmission for Multi-Cell MIMO Networks

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Abstract In this paper, we introduce a Hadamard matrix interstream transmission based blind channel estimation for multi-cells multiple-input and multiple-output (MIMO) networks. The proposed scheme is based on a network with mobile stations (MS) which are deployed with multi cells. We assume that the MS have the signals from both cells. The signal from near cell are considered as desired signal and the signals from the other cells are interference signal. Since the channel is blind, so that we transmit Hadamard matrix pattern pilot stream to estimate the channel; that gives easier and fast channel estimation for large scale MIMO channel. The computation of Hadamard based system takes only complex additions, and thus the complexity of which is much lower than the scheme with Fourier transform since complex multiplications are not needed. The numerical analysis will give perfection of proposed channel estimation.

Key Words : Blind Channel Estimation, Hadamard Matrix, Multi Cell, Hadamard Interatrial Sequence.
I. Introduction

Due to the extremely growth in wireless communication services in the last decade, there has been an increasing demand of new resources. Multiple-antenna communications systems have generated a great deal of interest since they are capable of considerably increasing the capacity of a wireless link. Recently, coordinated multiple point has been considered as an efficient technology to eliminate the inter-cell interference\[1\].

Small Cells networks have introduced to describe the characteristics of all sorts of radio cells such as femto, micro, pico-cells. The channel estimation in small-cell networks are becomes an important issue to the researcher throughout the world. Channel estimation is one of vital parts of mobile wireless channel. Channel estimation is a method used to significantly improve the performance of the system, especially for 4G Long Term Evolution (LTE)\[2\]. Since the channel is assumed to be blind in this paper, the base stations (eNBs) must transmit training sequences; being orthogonal among the antennas of different sectors and sites.

In order to estimate the channels of interferers, the base stations (BSs) must transmit training sequences being orthogonal among the antennas of different sectors and sites. On the other hand, quite a lot of these channels must be estimated to combat the interference until the noise floor is reached. The more interferer channels are distinguishable, the more orthogonal pilots must be transmitted. This consumes a large fraction of the potential capacity gain. In this paper, In this paper, we propose a Hadamard matrix interstream transmission based blind channel estimation for multi-cells networks. Hadamard matrix pattern gives easier and fast channel estimation for large scale MIMO channel. Our proposed scheme does not consume any more pilots than in current systems. But it enables mobile terminals to distinguish the more of the strong interference channels the slower they are moved in the service area. Hence, without increasing the pilot overhead, low-mobility terminals can take most benefit of advanced interference mitigation schemes.

The rest of the paper is organized as follows. In Section II, we introduce the proposed system models. In subsection of II, proposed channel estimation is introduced. We provide simulation results comparing the conventional scheme in Section V, and close by discussing conclusions in Section VI.

II. System Model

We consider a multi-cell downlink system with multiple a base station(eNB) in each cell. There are \(N\) cells comprising with \(K\) mobile user (MS). As an example, two-cell and single user system is shown in Fig. 1. As shown in Fig. 1 a mobile user are receiving signal from both cells eNB. According to the Fig. 1, the received signal at MS in \(i\)-th time slot using Alamouti scheme\[3\] is written as

\[
y_i = h_r x_i - h_r x_i^* + z_i, \quad (1)
\]

\[
y_2 = h_r x_2^* + h_r x_1 + z_2, \quad (2)
\]

where \(r_i\) and \(r_j\) are the received signal at time slot \(t = T\) and \(t = 2T\), \(h_r\) and \(h_l\) are the channel
The coefficient from desired and interference cell eNBs respectively, and \( z_1 \) and \( z_2 \) are the white gaussian noise with zero mean and variance \( n_v \), namely, \( n_v \sim \mathcal{CN}(0, N_z) \). For the multi cells system we do the same thing as above. The multi cells transmission scheme is shown in Fig. 2.

Fig. 2  A multi-cell example with one mobile station (MS) and eNB in each cells. Each cells eNB transmits Hadamard pattern pilot stream to MS.

**A. Hadamard Pattern Pilot Transmission**

For the blind channel, (i.e.) the transmitter does not have the channel state information (CSI), the pilot symbol is transmitted using Hadamard pattern for the channel estimation. In the similar way as (1) and (2), the pilot symbols received at the receiver at time slot \( t = T \) and \( t = 2T \) can be calculated as

\[
P_1 = H_d S_x + H_i S_x + N_1 \tag{3}
\]

\[
P_2 = H_d S_x - H_i S_x + N_2 \tag{4}
\]

where \( H_d \) and \( H_i \) is the real part of channel coefficient of \( h_d \) and \( h_i \). From (3) and (4) the Hadamard matrix pilot sequence \( \{ S_x, -S_x \} \) is used. In this part, to simplify the channel estimation we ignore the noise part in (3) and (4). Adding (3) and (4) we have the pilot symbol \( P_1 + P_2 = 2H_d S_x \). Now the estimated channel can be written as

\[
\hat{H}_d = \frac{P_1 + P_2}{2S_x} \tag{5}
\]

where \( \hat{H}_d \) is the estimated channel between desired eNB and MS. Similar way as (5), the estimated channel between interference eNB and MS can be calculated as

\[
\hat{H}_i = \frac{P_1 - P_2}{2S_x} \tag{6}
\]

For the multi–cell we extend the Hadamard matrix using the Kronecker product theory as[4]

\[
H_x = \begin{pmatrix}
H_{x_1}
& -H_{x_2}
\end{pmatrix}
\begin{pmatrix}
H_{x_1} & H_{x_2}
\end{pmatrix}
= H_x \otimes H_{x_2},
\]

As an example of Hadamard interstream blind channel estimation for higher order Hadamard matrix we consider \( 8 \times 8 \) Hadamard matrix here. In this case, we suggest to apply Hadamard Stream sequences spread over the time domain from slot to slot with a maximum sequence length of 8. Here, each row of a block–orthogonal sequence matrix is orthogonal to all other rows of the same matrix with full correlation length, i.e. \( r^H = I \). Note that the suggested scheme can be easily extended to the case of larger order Hadamard matrix length. Let us now see how Hadamard matrix work. To do the estimation we use dimensional Hadamard transform. Assuming we deploy enough pilots, the LS estimation of channel transfer function, and each stream can be assembled into an \( M \times L \) matrix in frequency and time domain for two-dimensional Hadamard Transform.

After the first dimensional Hadamard Transform in frequency domain, energy of the channel tends to concentrate on the low end of the transform domain. Since HT is a linear transform, the energy of white Gaussian noise after HT remains uniformly distributed. In order to represent the two dimensional Hadamard Transform in a matrix form, the channel
transfer function matrix in time and frequency domains need to be converted to a long vector. The LS estimation vectors of channel can be written as

\[ \hat{H}_l = (\mathbf{b}_{1,l}^\top \mathbf{b}_{2,l}^\top \cdots \mathbf{b}_{L,l}^\top)^\top \]  

(7)

The first dimensional Hadamard Transform of \( \hat{H}_l \) in LS has now become:

\[ \hat{H}^{(1)}_l = \Gamma_a \cdot \hat{H}_l \]  

(8)

where

\[
\Gamma_a = \begin{pmatrix}
1 & 1 & 0 & \cdots & 0 \\
1 & -1 & 0 & \cdots & 0 \\
0 & 1 & 1 & \cdots & 0 \\
0 & 0 & 1 & \cdots & 0 \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
0 & \cdots & 0 & 1 & 1 \\
0 & \cdots & 0 & 1 & -1
\end{pmatrix}
\]

(9)

is a block diagonal matrix. In this case, \( \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \) could be a matrix of order \( n \). Each block Hadamard sequence is represent in each cell sequence. As an example of \( 4 \times 4 \) Hadamard sequence (9) can be represent as

\[
\Gamma_a = \begin{pmatrix}
1 & 1 & 1 & 1 \\
1 & -1 & 1 & -1 \\
1 & -1 & 1 & -1 \\
1 & -1 & 1 & -1 \\
0 & 1 & 1 & 1 \\
0 & 1 & -1 & 1 \\
0 & 1 & -1 & 1 \\
0 & 1 & -1 & 1
\end{pmatrix}
\]

(10)

For \( n-th \) cells we will use \( n \times n \) block Hadamard stream sequence. We simplify the equation (10) as

\[
\Gamma_a = \begin{pmatrix}
\alpha_l & 0 & \cdots & 0 \\
0 & \alpha_l & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
0 & \cdots & 0 & \alpha_l
\end{pmatrix}
\]

(11)

where \( \alpha_l \), \( n-th \) order block diagonal Hadamard matrix and \( \alpha_l \) is the \( N \times N \) real symmetric core matrix.

In Fig. 3 the decimal numbers indicate the sector index. The Hadamard sequences spread over space (rows) and time (columns) domain. Hex-base numbers indicate sites with the same virtual pilot sequence. It is not difficult to show the orthogonality of \( H^{(1)}_l \), \( n=1,2,\cdots,n \) that is \( n-th \) order Hadamard transform. The 2-D Hadamard Transform can be written as

\[ Y = H_s X H_s \]

\[ X = H_s Y H_s. \]

(12)

Now the first order estimated channel can be written as

\[ \hat{H}^{(1)}_l = \Gamma_a \cdot \hat{H}_l. \]

(13)

Then, in (8) \( B_l^{(1)} \) is interleaved for the Hadamard Transform, as

\[ \hat{H}^{(2)}_l = K \cdot \hat{H}_l^{(1)}. \]

(14)

where \( K \) is a sparse matrix, with the element

\[ k_{i,j} = \Gamma_{i,j}^{(1)}. \]

(15)

Consequently, the 2-D Hadamard Transform has now become

\[ \hat{H}^{(2)}_l = \Gamma_a \cdot \hat{H}_l^{(1)}. \]

(16)
where
\[
\Gamma_z = \begin{pmatrix}
\omega_0 & 0 & \ldots & 0 \\
0 & \omega_0 & \ldots & 0 \\
\vdots & \ddots & \ddots & \vdots \\
0 & \ldots & 0 & \omega_0 \\
\end{pmatrix}
\]
(17)
is also a \( n \times n \) order block diagonal Hadamard matrix and \( \omega_z \) is the \( N \times N \) real symmetric core matrix of one-D Hadamard Transform.

After the MMSE weighting in the 2D Hadamard Transform domain, and the 2D Inverse Hadamard Transform, the channel transfer function in frequency domain becomes
\[
\hat{H}_{mmse} = \Gamma_x K^T \Gamma_x G \Gamma_x \tilde{H}_t
\]
(18)
where \( \Gamma_x \) is a block diagonal matrix for the 2D Inverse Hadamard Transform, \( \Gamma_z - \Gamma_x \) is a block diagonal matrix for the first-dimensional Inverse Hadamard Transform and \( Q = \text{diag}(q) \) diagonal weighting matrix for MMSE weighting.

### B. Covariance estimation based Hadamard interstream transmission

Now we estimate our system based on covariance matrix for Hadamard interstream transmission. One may think of two simple mechanisms to estimate the desired matrix. Now, we can simplify (1) and (2) as vector form as
\[
y = \mathbf{h}_z \mathbf{x}_d + \mathbf{h}_z \mathbf{x}_i + \mathbf{z}
\]
(19)
where \( y = [y_1, y_2]' \), \( \mathbf{x}_z = [x_z - x_i]' \), and \( \mathbf{x}_i = [x_i, x_i]' \).

On the one hand it is possible to obtain this knowledge by estimating the covariance matrix \( Q = E[y'y] \) of the received signal vector \( y \) using several subsequently received data symbols. The Hermitian transpose and expectation operators are denoted by \( (\cdot)' \) and \( E[\cdot] \), respectively. For proper application it is necessary to know the system’s covariance matrix defined as
\[
Q_y = E[yy'] = E[(\mathbf{h}_z \mathbf{x}_d + \mathbf{h}_z \mathbf{x}_i + \mathbf{z})(\mathbf{h}_z \mathbf{x}_d + \mathbf{h}_z \mathbf{x}_i + \mathbf{z})']
\]
(20)
\[
= E[\mathbf{h}_z \mathbf{x}_d \mathbf{h}_z'] + E[\mathbf{h}_z \mathbf{x}_i \mathbf{h}_z'] + E[\mathbf{z} \mathbf{z}']
\]

### C. Hadamard Sequence compared with the Least Square (LS) and Minimum Mean Square Estimation (MMSE)

Here we consider MS is close to the interference cell. Considering the interference signal and the desired signal from the both of the cells, we can simplify (1) and (2) as vector form as
\[
y = \mathbf{h}_z \mathbf{x}_d + \mathbf{h}_z \mathbf{x}_i + \mathbf{z}
\]
(21)
where \( y = [y_1, y_2]' \), \( \mathbf{x}_z = [x_z - x_i]' \), and \( \mathbf{x}_i = [x_i, x_i]' \).

Since, MS is close to the interference eNB, we can ignore the interference cells signal and we can write (7) as
\[
y = \mathbf{h}_d \mathbf{x}_d + \mathbf{z}
\]
(22)
The LS estimation of \( \mathbf{h}_z \) is to minimize the squared difference between observation, \( y \), and the model output without noise\(^6\). Now the LS estimation can be calculated as
\[
\hat{\mathbf{h}}_{LS} = \arg \min_{\mathbf{h}} \| y - \mathbf{h}_d \mathbf{x}_d \|^2,
\]
(23)
The MMSE estimation is provided reasonably good performance with less statistical information. The goal is to estimate the channel \( \mathbf{h}_z \) from the knowledge of \( y \) and \( \mathbf{x}_z \). Consider the linear model in (8) where the sequence \( \mathbf{x}_z \) is known, and after some mathematical manipulation the MMSE estimation is given by
\[
\hat{\mathbf{h}} = yx_z y'(R^{-1} + x_z x_z y')^{-1},
\]
(24)
where \( A \) is the autocorrelation of \( \mathbf{h} \). Now the mean square estimation error can be calculated as
\[
\Gamma_{\text{mean}} = E[\| \mathbf{h} - \hat{\mathbf{h}} \|^2] = tr(R^{-1} + x_z x_z y')^{-1}
\]
(25)
III. Simulation

In the simulation, we perform the monte-carlo simulation to show the performance of our proposed scheme with compare to some well-known channel estimation techniques. In Fig. 2, we can see the performance of proposed Hadamard sequence that is with the conventional LS and MMSE estimation along with Weighted Least Square (WLS) estimation. In Fig. 3, Computation Complexity of Hadamard based estimation and LS Estimation is compared. It is shown that, the Hadamard sequence estimation is more better performance than that of LS estimation while the MMSE is till perform better. But the computation complexity of Hadamard sequence is less than that of LS estimation and Hadamard matrix will become more practical channel estimation scheme.

IV. Conclusion

In this paper, we introduce a Hadamard matrix interstream transmission based blind channel estimation for multi-cells multiple-input and multiple-output (MIMO) networks. We expect that the proposed algorithm based on Hadamard sequence will become more practical channel estimation scheme for OFDM systems.

References


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※ This work was supported by MEST, 2015R1A2A1A05000977, NRF Korea.